Modelling Of Machinery Vibration Isolation Systems

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1. INTRODUCTION

The VVES (Vibration of Viscoelastic and Elastic Structures) suite of MATLAB programs was developed to predict the 3D vibration and isolation characteristics of machinery mounted on one or more layers of elastomeric isolators [1, 2]. The layers can be separated by rigid rafts or flexible rafts formed from a grid of elastic beams. The properties of isolators can be computed within the program for simple flexible component shapes using the viscoelastic material properties. Alternatively, overall mount properties can be entered into the model. This is useful where isolation mounts have complicated geometry and/or are under significant static compression. Measured individual mount properties or detailed finite element predictions can then provide accurate input dynamic characteristics. The suite of codes has a large number of input files and limited visualization capabilities. A graphical user interface called VIMGEN (Vibration Isolation Model Generator) has been developed by DRDC Atlantic and Martec Limited [3] which allows system models to be generated quickly with fewer errors using wizards and interactive detailed 3D graphics. This paper describes the capabilities of the VVES and VIMGEN codes and compares predictions with small-scale experiments [4].

2. THE VVES MODEL

VVES is a 3D finite element modelling tool with a limited number of element types, specialized for efficient modelling of low frequency dynamic behaviour of vibration isolation systems. The program can calculate the vibration modes and natural frequencies of a system, and the steady state response to user defined forces applied to an engine "block". VVES can also calculate the "quasi-static" response of a system caused by motion of the machinery foundation, for example, on a ship in a seaway. The engine or machine to be isolated is assumed to be a rigid body. A centre of gravity, mass moments of inertia, and any number of user-defined attachment points define the engine "element". Elements that can be connected to the attachment points include vibration isolators, elastic beams and point masses. The system can also contain rigid raft elements defined in a manner similar to the engine element. Flexible rafts can be considered using a grid of elastic beam elements.

Three "flavours" of VVES have been developed, each employing a different approach to the modeling of the isolators: i) an approach based on finite element analysis of the viscoelastic isolators using constitutive data of the isolator material; ii) an approach based on the determination of the constitutive data from the results of dynamic stiffness measurements conducted on engine mounts; and iii) an approach based on the results of so called 4-pole parameter data that describes the velocity force transfer matrices measured on full sized mounts in a given direction. A fourth version of VVES has been developed for consideration of active vibration isolators. Only the first version will be discussed further in this paper.

At the global level, each vibration isolator is considered as a single finite element with two attachment nodes, each node having three displacement and three rotational degrees of freedom. The isolator element can have any orientation in space as defined by the attachment nodes and a third point providing the orientation about a line through the attachment nodes. The 12x12 dynamic stiffness matrix $\mathbf{Z}_v$ for the isolator element is formed according to Equation 1 as a function of frequency ω,

$$\mathbf{Z}_v(\omega) = G_1(\omega)\mathbf{K}_{v1} + G_2(\omega)\mathbf{K}_{v2} - \omega^2 \rho \mathbf{M}_v, \quad (1)$$

where $\mathbf{K}_{v1}$ and $\mathbf{K}_{v2}$ are element stiffness matrices and $\mathbf{M}_v$ is the element mass matrix. $G_1(\omega)$ and $G_2(\omega)$ are respectively the complex shear and complex bulk moduli of the elastomeric material. The elastomeric materials typically used in vibration isolators are nearly incompressible and the above formulation eliminates numerical problems that can occur in formulations using Young's modulus and a Poisson's ratio $\mathbf{v}$ that approaches 0.5. The material moduli $G_1(\omega)$ and $G_2(\omega)$ can be measured using dynamic-mechanical testing of small samples of the isolator material. $\mathbf{K}_{v1}$, $\mathbf{K}_{v2}$ and $\mathbf{M}_v$ are only dependent on the isolator geometry and are calculated within VVES for elements with the geometry shown in Figure 1. For isolators of more complicate shaped, if it is assumed that $\mathbf{v}$ is independent of frequency, then $\mathbf{K}_{v2} = 0$ and $\mathbf{K}_{v1}$ can be derived from an external "standard" elastic finite element analysis and imported into VVES.

Fig. 1 Isolator shapes modelled within VVES.

3. VIMGEN MODEL GENERATOR

VVES provides simple line drawings of the engine and rafts. Isolators and beams are drawn as lines between nodes. This drawing is only produced after creation of all ASCII input files defining the VVES model geometry. This is not very useful for checking purposes. VIMGEN has a user-friendly Windows-based interface that allows model data to be entered easily with forms and wizards. As geometric information is entered, the updated model can be viewed in realistic 3D shaded graphics with mouse controlled movement and interaction with model components. VIMGEN can generate input files, run the VVES code and provide 3D animated graphics of system vibration modes and response. It can also provide graphs and tables of results. VIMGEN was developed using a suite of C++ tools call HOOD (Hierarchical Object Oriented Developers tool kit) developed at DRDC to allow rapid generation of engineering modeling and visualization software.

4. SMALL-SCALE EXPERIMENT

As part of testing of VVES and VIMGEN, predictions for some small-scale isolation systems have been compared with measurements made by the Defence Science and Technology Organisation (DSTO), part of Australia's Department of Defence [4]. These systems consisted of 25 mm x 50 mm x 24 mm rubber isolators sandwiched between steel plates. The systems were suspended axially from a soft string in a free-free state. Two VIMGEN/VVES models are shown in Figure 2. The first (A) consists of a single isolator between two 60 mm x 60 mm x 24 mm steel plates. The second (B) has 4 isolators between two 120 mm x 120 mm x 24 mm steel plates. A single "very soft" isolator (shown as a vertical line element) connects the lower steel plate to a rigid base foundation, achieving essentially a "free-free" system. A third two-stage model similar to model "B" but with an additional steel plate and a second layer of four isolators has been built but not tested to date.

The frequency dependent dynamic-mechanical properties of the rubber material were measured at the DRDC Atlantic Dockyard Lab and used in the VVES models. The Young's modulus of the material varied from 3.4 MPa at 1 Hz to 3.9 MPa at 300 Hz. The loss factor of the material varied between 0.03 at 1 Hz to 0.05 at 300 Hz. A comparison of measured and predicted natural frequencies for models "A" and "B" is given in Table 1. The lateral direction refers to the long dimension of the isolators. Figure 3 shows some of the modes shapes predicted by VVES for Model A and viewed with VIMGEN.

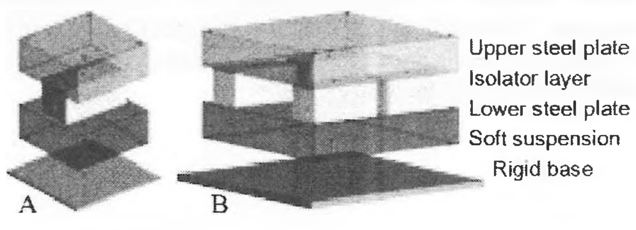

Fig. 2 VIMGEN models of vibration isolator systems.

Table 1. Free-free system natural frequencies

Mode Shape	Model	Pred. (Hz)	Meas. (Hz)	Diff. (%)
Axial rotation:	A	42.0	38.9	5.6
(about the vertical)	B	68.8	69.0	-0.3
Lateral translation:	A	106.9	100.0	6.9
(shear)	B	77.1	76.9	0.3
Transverse translation:	A	96.2	92.7	3.8
(shear)	B	69.1	72.9	-5.2
Lateral rotation:	A	49.0	48.6	0.8
(tension/compression)	B	165.6	157.2	5.3
Transverse rotation	A	100.2	NA*	
(tension/compression)	B	126.8	114.9	10.4
Axial translation	A	139.7	134.9	3.6
(vertical direction)	B	136.4	NA	

*Measurements show "diagonal" rotational modes at 93.4 Hz and 100.4 Hz

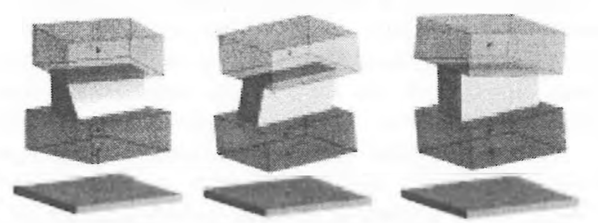

Fig. 3 VIMGEN views of VVES predicted mode shapes.

5. CONCLUSION

Computer codes VIMGEN and VVES have been developed for modelling the 3D characteristics of vibration isolation systems containing elastomeric isolator elements. The codes have been described and a study of the modes of a small-scale system provided. Further work is underway including predictions and measurement of vibration transfer functions for both small-scale systems and for actual diesel engine isolation systems.

REFERENCES

[1] S.G. Hutton, J.P. Szabo, and D. Stredulinsky, "Selection of vibration isolation mounts for shipboard diesel engines", INTER-NOISE 98, Christchurch, New Zealand, November 16-20, 1998.

[2] S.G. Hutton, "Optimization of vibration mount properties for application to shipboard diesel engines - Phase III", DREA Contractor Report, CR 2000-077, January 2001.

[3] M.F. Polak, L. Jiang, L., T.A. McAdam, and M.W. Chernuka, "Development of a model generator and graphical user interface for the VVES Programs", DREA Contractor Report, CR 2001-143, January 2002.

[4] J. Forrest (private communication), DSTO Aeronautical and Maritime Research Laboratory (AMRL), Melbourne, Australia.